DE-FE0031979
Advanced Dry-cooling with Integrated Enhanced Air-Cooled Condenser and Daytime Load-shifting Thermal Energy Storage for Improved Power-Plant Efficiency

2021 DOE/FE Spring R&D Project Review Meeting – 17 May 2021

Raj M. Manglik

Principal Investigator; University of Cincinnati

UNIVERSITY OF Cincinnati

Project Team

Raj M. Manglik (Principal Investigator)
Milind A. Jog (Co-PI)

Andrew Howell (Industry Partner)

Jean-Pierre Libert (Industry Consultant)

Maulbetsch Consulting

John S. Maulbetsch (Consultant)

Background / Motivation

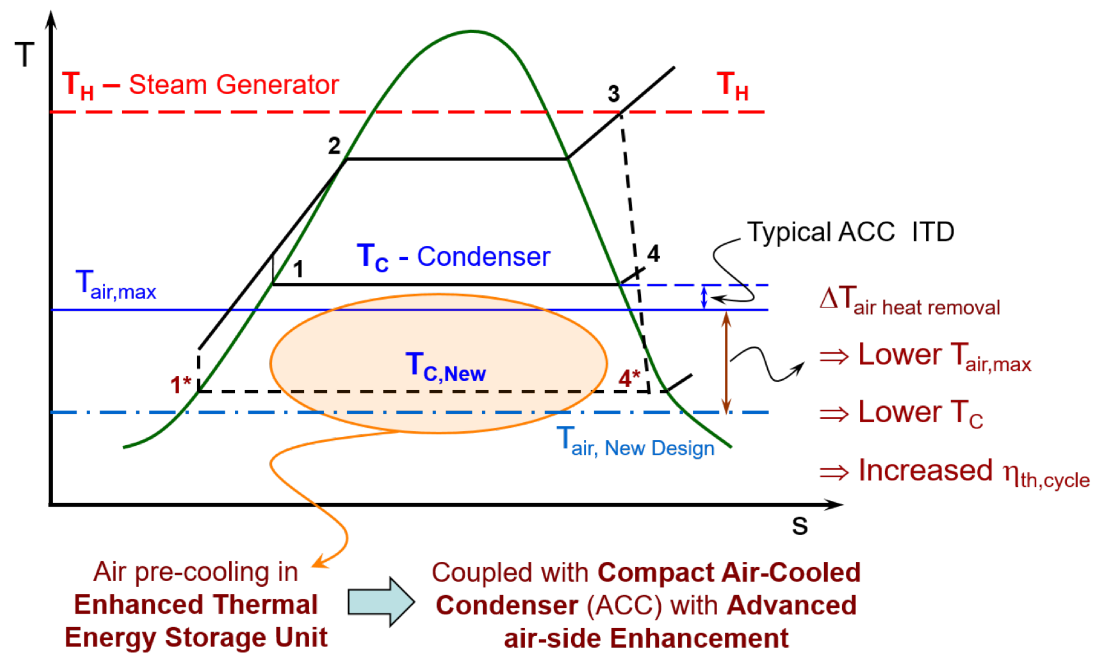
Air-Cooled Condenser (ACC)

- Large parts of the US are expected to experience water stress over next two decades
- Need disruptive technologies to reduce water usage in one of the largest consumer of fresh water (wet cooling for electricity generation)
- Make dry-cooling systems (ACCs) more effective
  - Enhance the low air-side heat transfer coefficient and reduce footprint
  - Mitigate the thermodynamic limitations on performance when daytime peak ambient temperatures are high.

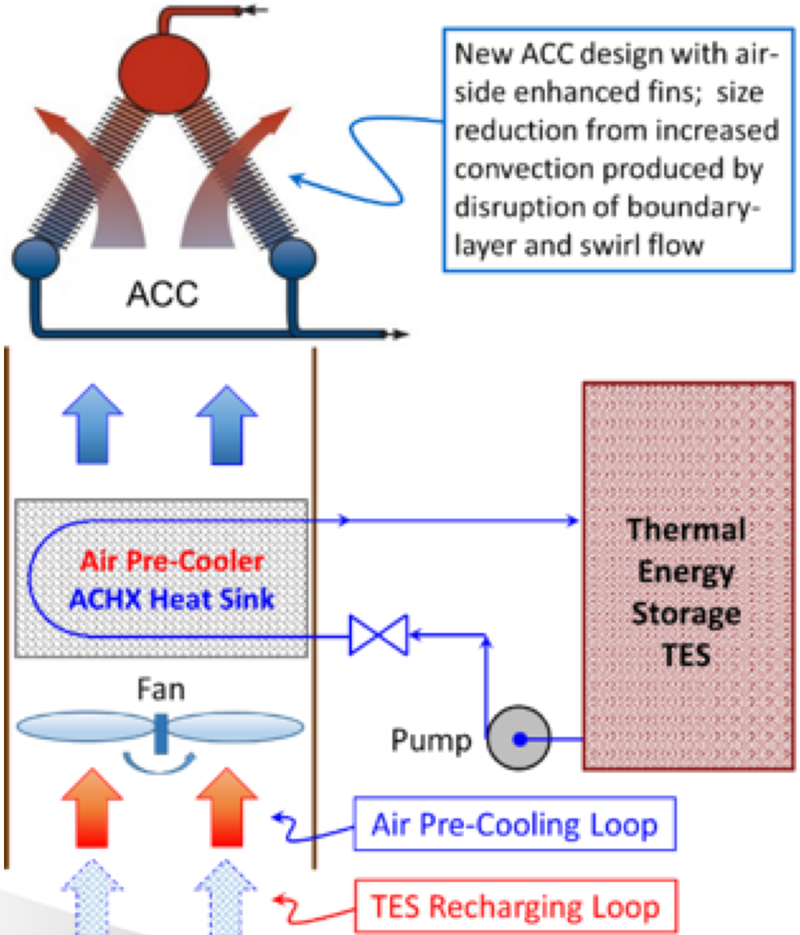
Background / Motivation

Impact of limitations due to high daytime ambient temperature on dry- or air-cooling in fossil fuel power plants:

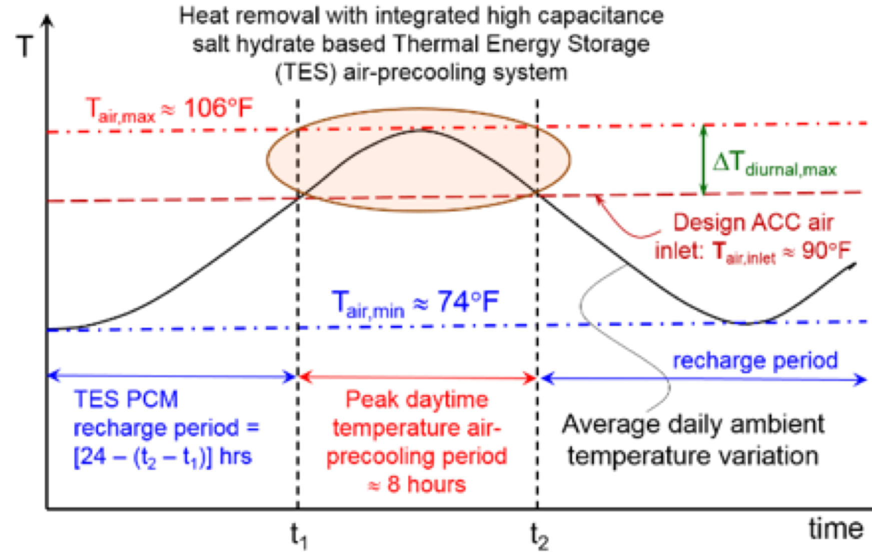
- ACCs are over-sized with a large initial temperature difference (ITD); condenser pressure is correspondingly higher.
- Increases both capital cost and operating cost.
- Yields low Rankine cycle thermodynamic efficiency at peak period of electricity demand.



Technology Innovation



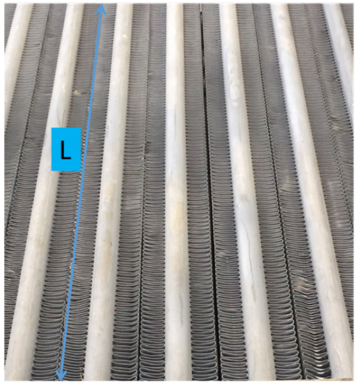
- Air-cooled condenser (ACC) with novel enhanced surfaces
- Inlet-air pre-cooling asynchronous thermal energy storage (TES) system



ACC Performance Enhancement –

Reduce Size of ACC (based on fixed power and pressure drop constraint)

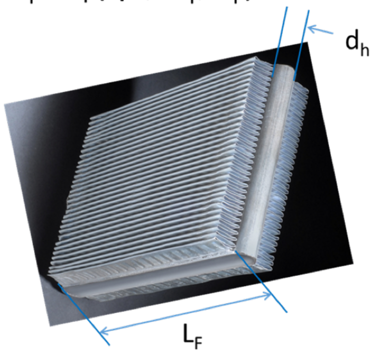
Fixed pressure drop constraint
(fixed heat transfer rate)



N = # tubes

$A = \phi(N, d_h, L, A_F, L_F)$

$A_F = \phi(fpi, H_F, L_F)$



$$\Delta p = f\left(4L/d_h\right)\left(\rho u_m^2/2\right) = \left(2\mu^2 L/\rho d_h^3\right)\left(f\,\mathrm{Re}^2\right)$$

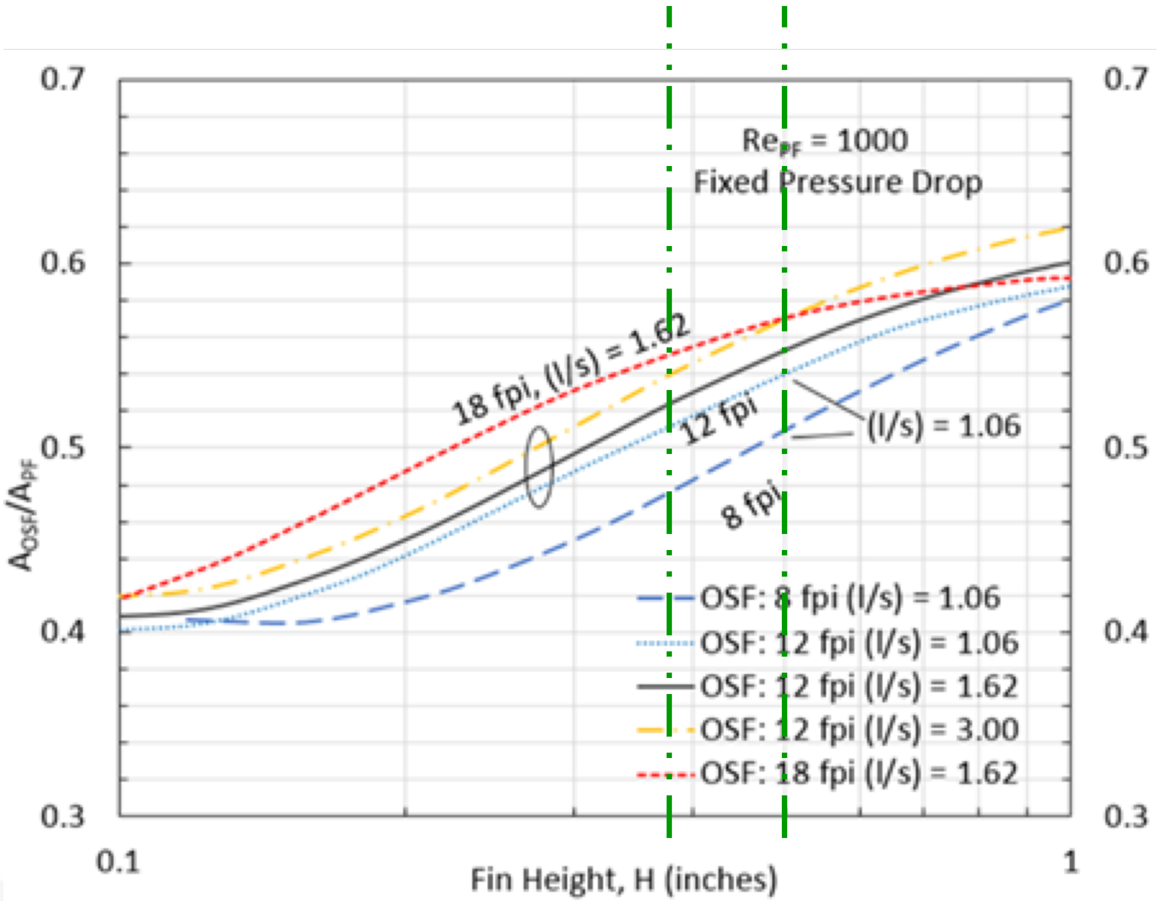
$$\left(f\,\mathrm{Re}^2\right)_{PF} = \left(f\,\mathrm{Re}^2\right)_{EF}$$

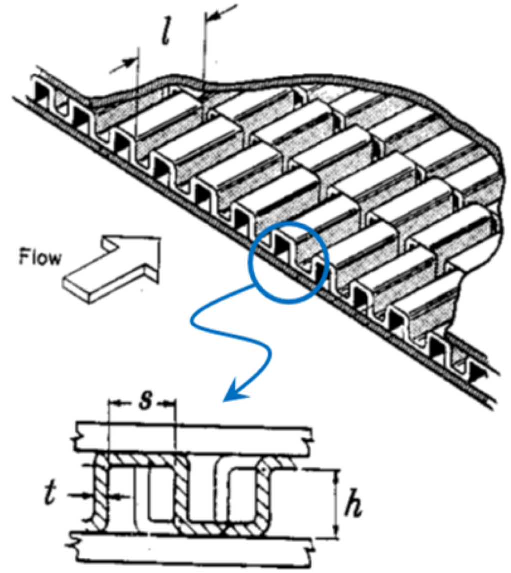
$$Q = \left(UA\right)\Delta T_m \approx \left(hA\right)_{air}\Delta T_i = \left(kP_t NL\Delta T_i/d_h\right)\mathrm{Nu}$$

$$\left(A_{EF}/A_{PF}\right) = \left(\mathrm{NTU}_{PF}/\mathrm{NTU}_{EF}\right)_{Q,\Delta T,\Delta p,d_h} = \left(h_{PF}/h_{EF}\right)_{Q,\Delta T,\Delta p,d_h}$$

ACC Performance Enhancement –

Reduce Size of ACC (based on fixed power and pressure drop constraint)





Offset-Strip Fin (OSF) Cores

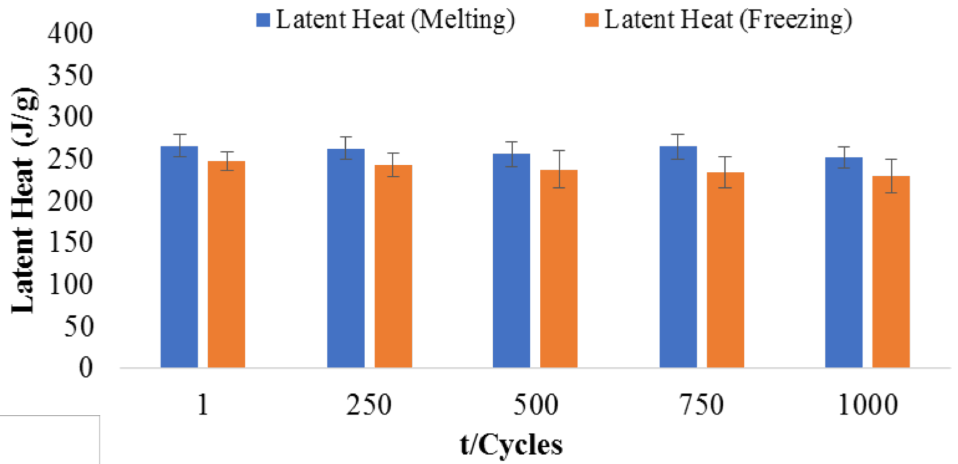
TES Design and Performance –

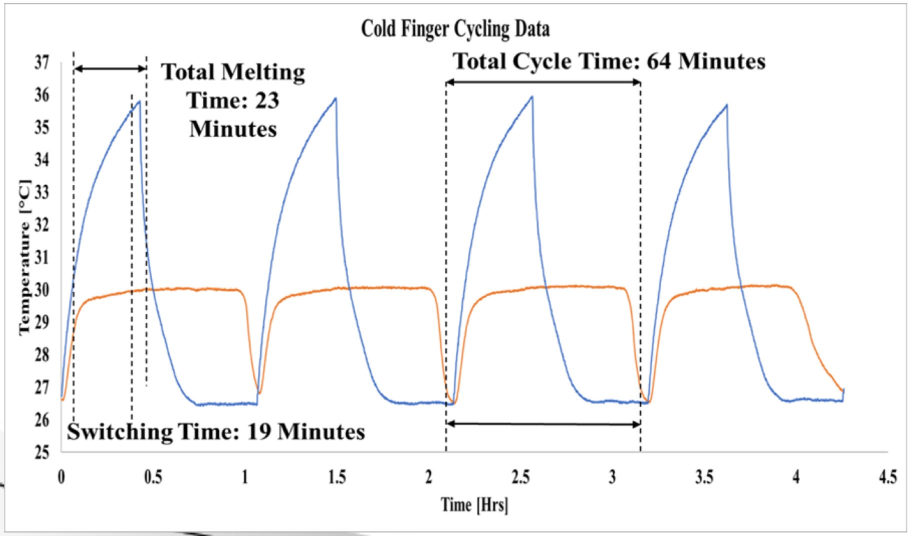
Phase-Change Material (PCM) Selection; Salt Hydrates

PCM	T_{sf} [°C]	ΔT_{sc} [°C]	h_{sf} [kJ/kg]	h_{sf} [kJ/m³]	Comments
Lithium Nitrate Trihydrate	29.2	3.8	273	650	✔
Calcium Chloride Hexahydrate	29.8	5.9	182	311	High Corrosion
Zinc Nitrate Hexahydrate	34.6	3.1	140	290	High T_{sf}
Sodium Sulfate Decahydrate	32.2	25.2	233	341	Unstable

TES Design and Performance –
PCM ($LiNO_3 \cdot 3H_2O$) Stable Thermal-Cycling Performance

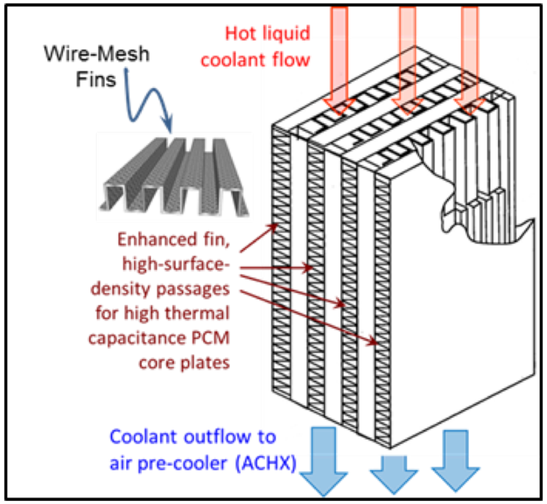
Stability of thermal capacity of $LiNO_3 \cdot 3H_2O$ over 1000 heating (dehydrating) and cooling (rehydrating) cycles

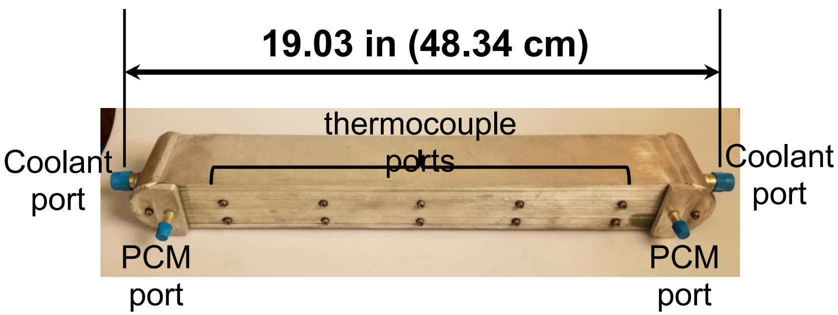




Self-seeded nucleation and phase-transition stability of $LiNO_3 \cdot 3H_2O$ during thermal cycling

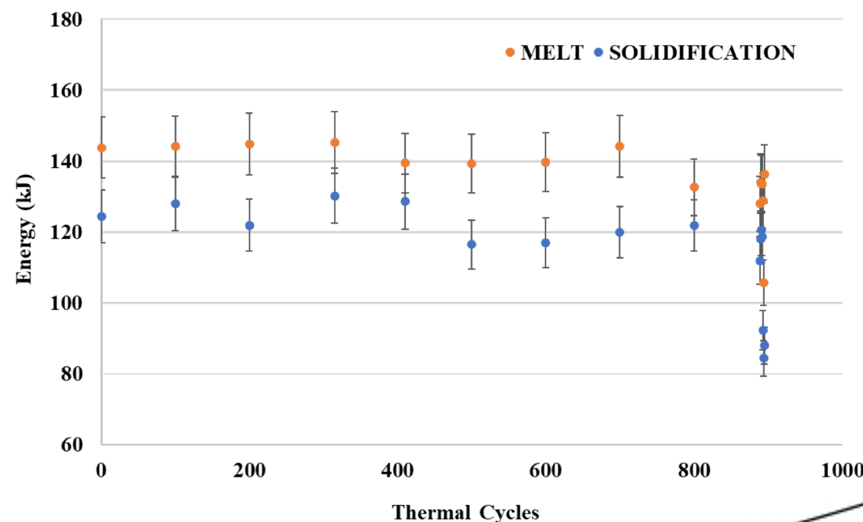
Lab-Scale (100 kJ) TES Module Design and Performance





100 kJ Lab-Scale Prototype TES HX

- TES PCM Encapsulation Matrix
  - Low-cost wire mesh fins for PCM channel
- Coolant Passages
  - Offset fin provides heat transfer enhancement in liquid passages



Project Objectives

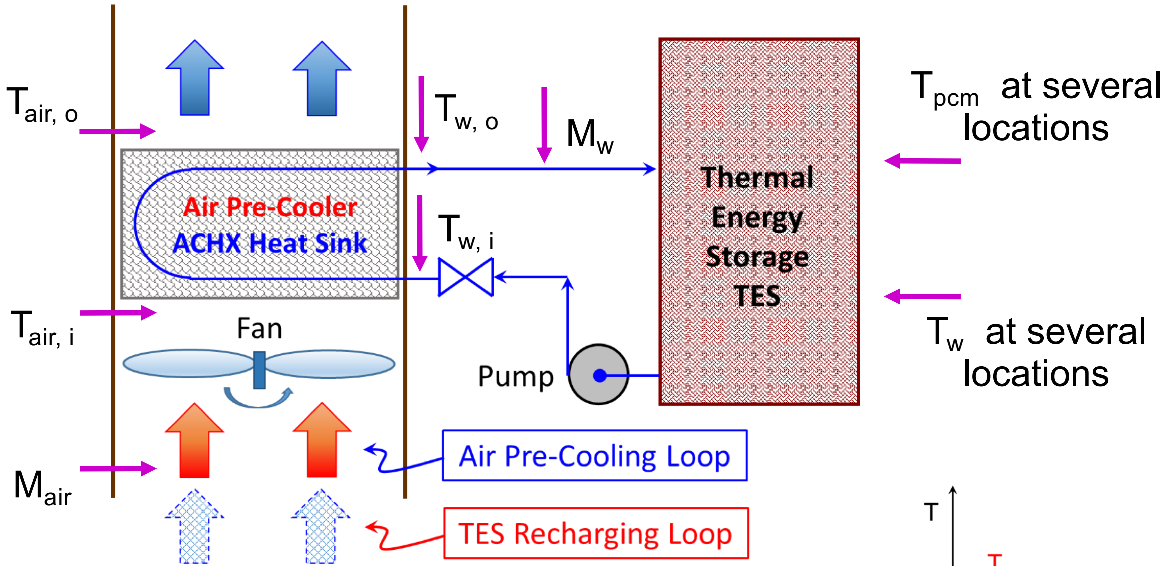
Develop (design, test, and scale up) a novel transformative air-cooling system which integrates a PCM-based thermal energy storage (TES) for pre-cooling of ambient inlet air to the air cooled condenser (ACC) during peak daytime hours, via a liquid coolant-to-air pre-cooler heat exchanger (ACHX)

- Task 1: Project Management and Planning
  - Overall management of the project as per the Project Management Plan -- UC
- Task 2: Design and Performance Evaluation of TES System
  - Design optimization of TES, Lab testing, and Scale up – UC, Evapco, EPRI
- Task 3: Design and Performance Evaluation of Air Pre-cooler
  - Design optimization and performance evaluation and Scale up – UC, Evapco, EPRI
- Task 4: Technology Demonstration
  - Fabrication and testing of pilot-scale system - EPRI
- Task 5: Techno-Economic Analysis
  - TEA Analysis – UC, Maulbetsch, Evapco, EPRI

UNIVERSITY OF Cincinnati

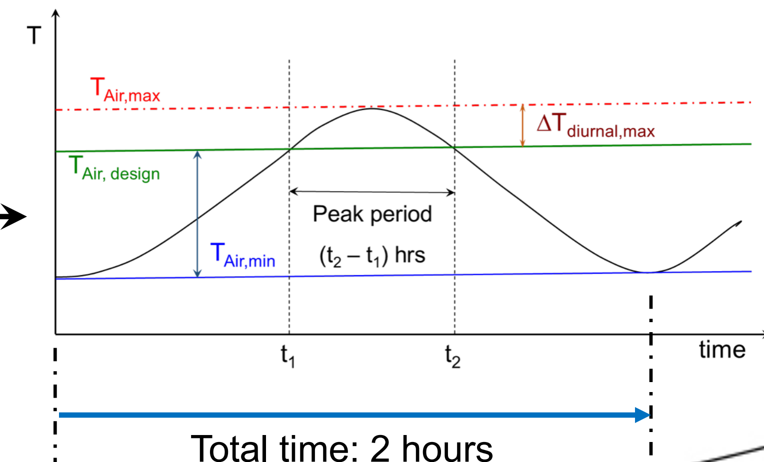
Preliminary TES Scale-up & Testing with Air Pre-Cooler

1.0 MJ TES + ACHX – with Air-Side diurnal temperature variations

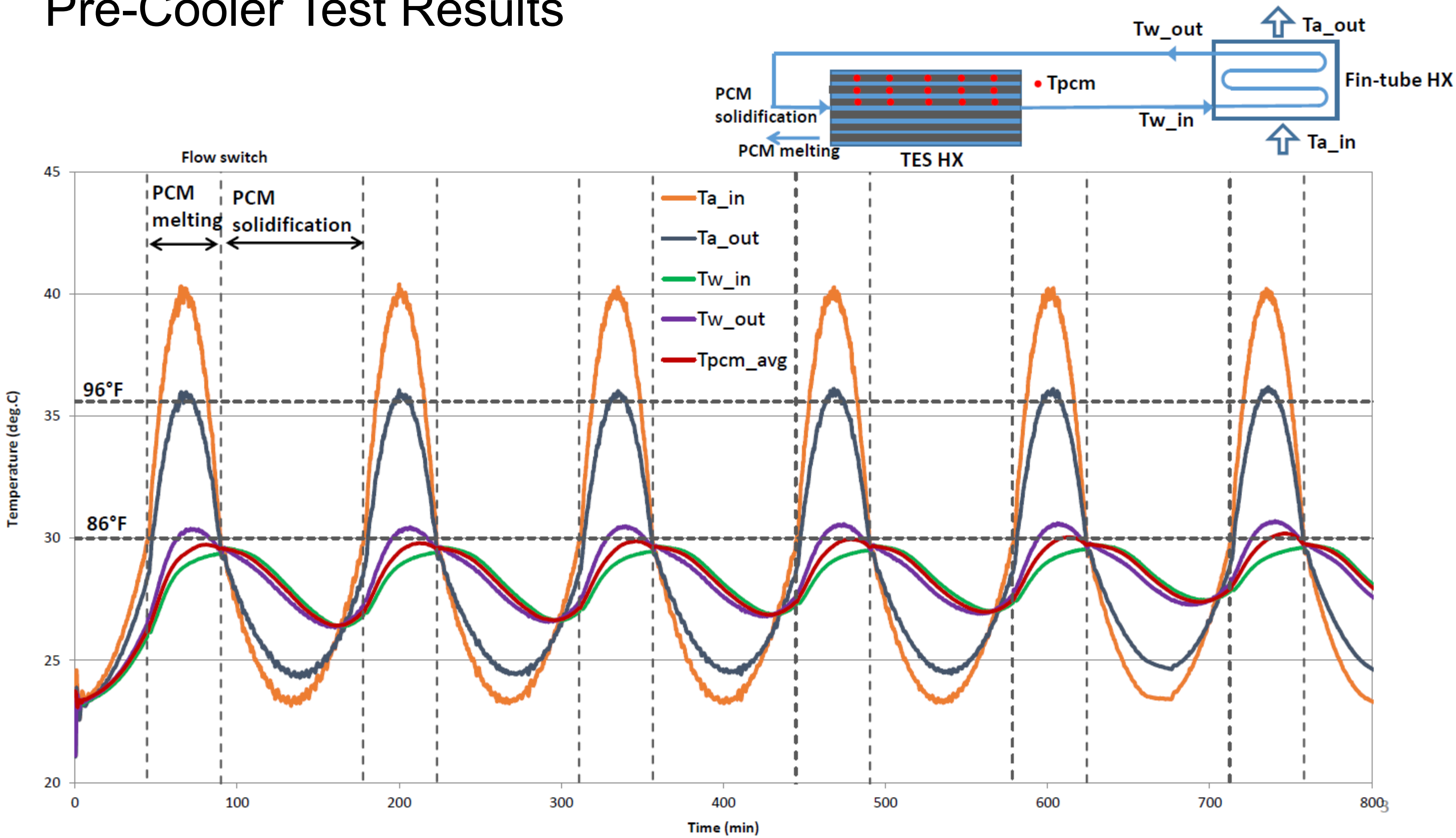


- TES scale-up (10× scale-up; 100 kJ → 1.0 MJ) and performance testing
  - Performance with diurnal air-side temperature variations (system-level prototype performance)

Inlet air – models diurnal temperature variation (Max 106°F, Min 74°F over a two-hour cycle)
Heating: 1 MJ over 40 min period; Cooling: 1 MJ over 80 min period; Air Pre-Cooler tube-fin heat exchanger size: ~ 420 W (or ~ 450 W, or can be overdesigned for testing purposes)



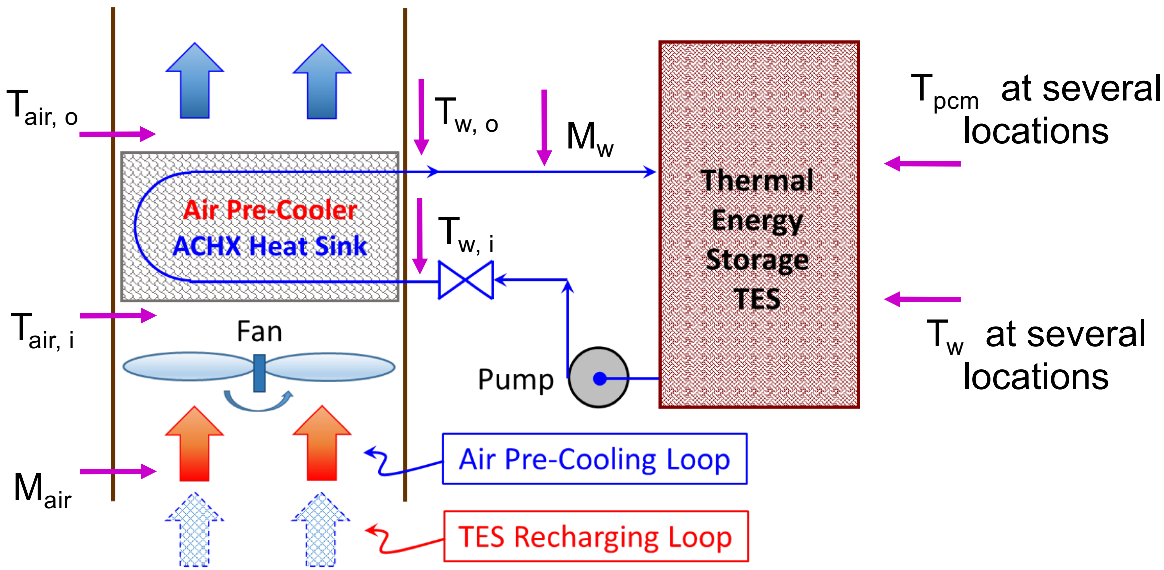
TES (1.0 M) HX and Air Pre-Cooler Test Results



UNIVERSITY OF Cincinnati

NEXT STEPS: TES Scale-up & Testing with Air Pre-Cooler

1.0 MJ TES + ACHX – with Air-Side diurnal temperature variations



- TES (1 MJ) redesign and performance testing
- Performance with diurnal air-side temperature variations (system-level prototype performance)

- Optimized Redesign of TES – consider an enclosed (brazed or welded) tube-fin heat exchanger and/or a semi-brazed and gasketted plate-and-frame heat exchanger.
- Reconfigure laboratory test set up and establish testing protocols for the redesigned TES coupled with air pre-cooler.

Acknowledgment: "This material is based upon work supported by the Department of Energy Award Number DE-FE0031979."

UNIVERSITY OF Cincinnati